MIAMI GEOLOGICAL SOCIETY MEMOIR 3

# SYMPOSIUM ON SOUTH FLORIDA GEOLOGY

edited by Florentin J-M R. Maurrasse

Miami Geological Society
P.O. Box 144333
Coral Gables, Fl 33114

December 1987

Sediments
report section maurrassee1987



# SEDIMENTS FROM A LIVING SHELF-EDGE REEF AND ADJACENT AREA OFF CENTRAL EASTERN FLORIDA

Charles M. Hoskin, John K. Reed and David H. Mook

Harbor Branch Oceanographic Institution
Marine Geology Department
5600 Old Dixie Highway
Fort Pierce, FL 33450

## ABSTRACT

Jeff's Reef (27° 32.5' N; 79° 58.3' W), a 16 m high *Oculina* coral bank on the shelf-slope break, is the site of modern carbonate sedimentation mixed with relict carbonate and quartz. Surficial sediments from the 94 $km^2$ surrounding area of outer shelf, shelf edge and upper slope are significantly different from reef sediments as judged by wt.% gravel, sand, silt, clay, mud, sorting, skewness and normalized kurtosis. Sand grain types (ooid + pellet + carbonate rock fragments, barnacles and coral) are also different for reef and non-reef areas. Sediments of non-reef origin in the adjacent areas have significantly larger between-station variance than within-station variance for the above grain size descriptors. These sediments have significant changes in grain size descriptors E-W, and no significant changes N-S.

Sediment on the eastern shelf (48m depth) is unimodal coarse-skewed sand; shelf-edge sediment (80m depth) is bimodal, coarse-skewed sand; and upper slope sediment (140m depth) is unimodal, fine-skewed sand. Gravel fractions of non-reef sediments are dominated by shells and shell hash. By volume, sand fractions are composed of detrital silicate 25.7%, ooids 9.4, pellets 10.6, carbonate rock fragments 4.5, molluscs 23.0, barnacles 2.2, forams 10.6, coralline algae 0.3, coral 0.2, echinoderms 2.2, and unknowns 11.0. Jeff's Reef sediments (70-80m depth) are polymodal gravelly sands with the gravel fractions composed mainly of broken *Oculina* branches (up to 70% by wt.). By volume, sand fractions are composed of detrital silicate 26.8%, ooids 4.3, pellets 6.7, carbonate rock fragments 3.8, molluscs 23.6, barnacles 7.3, forams 12.2, coralline algae 0.2, coral 1.1, echinoderms 3.3, and unknowns 10.0. Reef top sands contain significantly more coral and barnacles, and significantly less molluscs and carbonate rock fragments than the reef base.

Sediment originated from the reef contains more mud ($\bar{X}$ = 14.3%) than nearby shelf sediments at the same depth ($\bar{X}$ = 4.6%). Coral branch gravel is not transported from the reef but export of coral sand is detectable. Current velocities near the reef base exceed 15 cm $sec^{-1}$ 17% of the time in winter and 11% of the time in summer. A 2 km wide band of shell hash between 70-100 m is elongated N-S suggesting transport parallel to the coast.

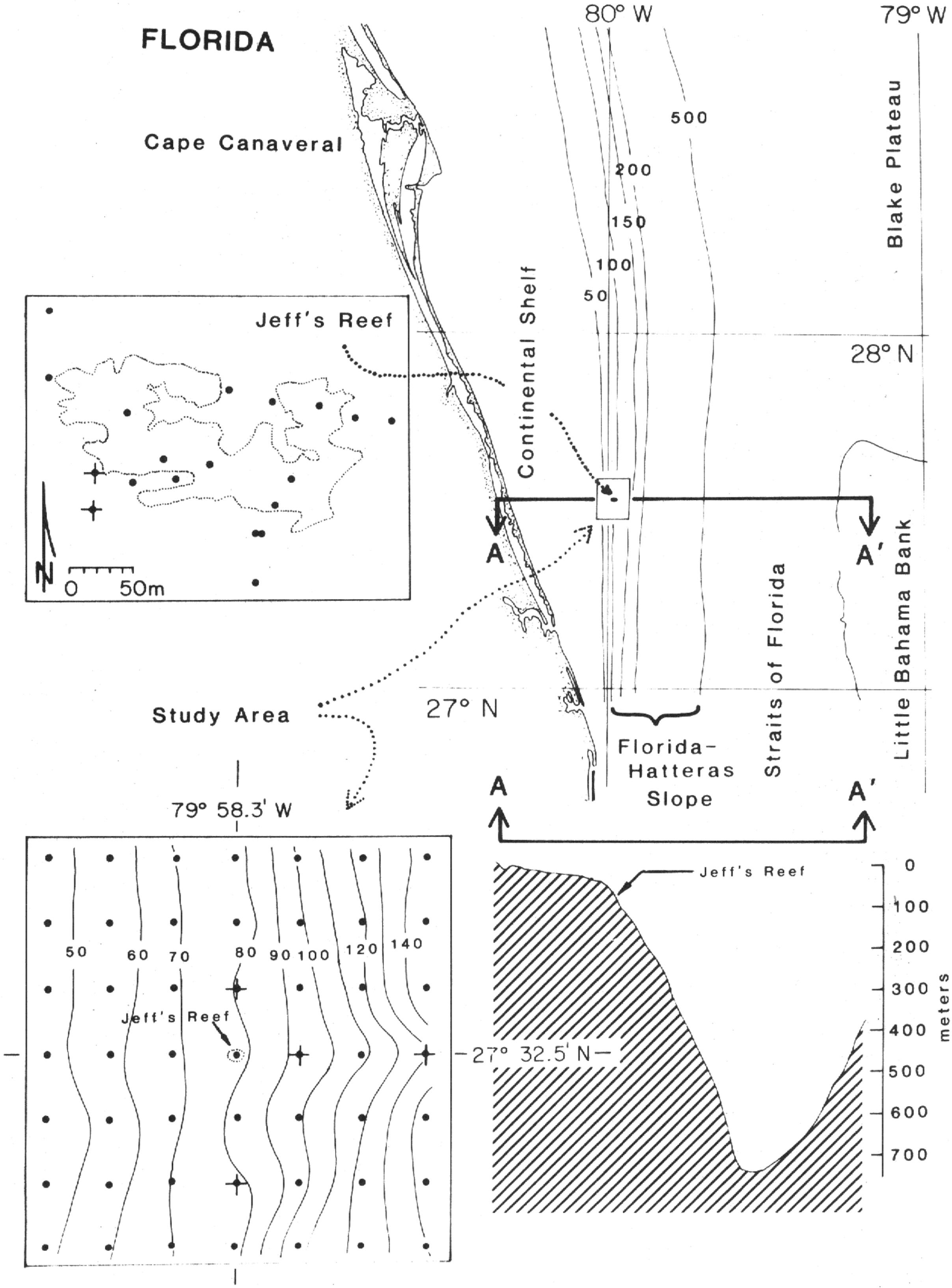


Figure 1 Index map of central eastern Florida (physiography after Uchupi 1969). Upper left inset shows Jeff's Reef with area of living Oculina inside sinuous line. Dots. show sample locations and dots with crosses are stations with replicate samples. Lower left inset shows entire study area with Jeff's Reef at center. Dots show sample locations as above. Bathymetric contour interval is 10m. Lower right inset is a bathymetric section from the coast eastwards through Jeff's Reef and partway up the western slope of the Little Bahama Bank. Vertical exaggeration = 137x.

## INTRODUCTION

Stony corals build limestone structures in two different environments: in shallow water, hermatypic reefs use sunlight as their direct energy source; in deep water, reefs and banks of corals lacking zooxanthallae (aposymbiotic corals) derive their energy from imported organic matter. Sediments associated with shallow-water reefs have been discussed by Ginsburg et al. (1965) and Shinn et al. (1977).

Due to difficulty of access, deep-water reefs are not well known. Teichert (1958) called attention to these coral structures, and sediment-related studies have been made by Stetson et al. (1962) and Scoffin et al. (1980). In the western Atlantic, deep-water reefs have been found at depths of 1000-1300 m off the Little Bahama Bank (Mullins et al. 1981) and 600-800 m in the Florida Straits (Neumann et al. 1977). Along the shelf edge of eastern Florida, banks aposymbiotic corals are abundant (Moe 1963, Macintyre and Milliman 1970, Reed 1980).

Sediments of the shelf edge off central eastern Florida are carbonate-rich (Gorsline 1963; Milliman et al. 1972) with much carbonate supplied through biogenic processes (Emery 1966). Along this shelf-slope break in a region of upwelling (Smith 1982), modern carbonate sediments are accumulating on reefs built by living *Oculina varicosa* Leseuer 1820, a branching scleractinian coral (Avent et al. 1977, Avent and Stanton 1979, Reed 1980, Thompson and Gilliland 1980, and Reed et al. 1982).

A 94 $km^2$ shelf-edge area centering on an isolated, living *Oculina* coral reef at a depth of 80 m (Jeff's Reef, 27° 32.5'N; 79° 58.3'W) is the study area of this report (Fig. 1). Jeff's Reef is the southernmost of the 200 km long area of living and dead reefs paralleling the 80 m bathymetric contour (Reed 1980). The reef is oval in plane view, 1000 m in circumference, and is elongated E-W across the Florida Current. Steepest slopes (30- 45°) face south and have the densest stands of live coral (Reed 1980). These features are believed to be the consequence of the prevailing northerly current. In contrast, the elongation of lithoherms at depths of 600-800 m in the Florida Straits parallel to northerly currents (Neumann et al. 1977) may reflect a higher proportion of reef-trapped sediment to framework or stronger currents than exist at Jeff's Reef. Growth rate of the coral branch tips is 16.1 mm $yr^1$(Reed (1981). The nature of the reef's substrate is not known; no rock outcrops have been seen on the reef, but limestone hardgrounds occur within 50 m to the SE. Mean salinity on the reef has been measured to be 36‰, the temperature ranges between 7.4 - 26.7° C with a mean of 16.2 °C, current speed ranges between 0 and 58.5 cm $sec^{-1}$ ($\overline{X}$=8.7), and mean percent of transmitted light is 0.33% (Reed 1981). Suspended particle concentration is 1.1-1.6 $mgl^{-1}$ a few meters off the bottom.

The purpose of this study is to determine in what ways Jeff's Reef has modified the local sedimentary environment, to quantitatively assess fine particle trapping by this living reef, and to identify any differences in constituent grain composition between shallow water hermatypic and deep water aposymbiotic coral reefs.

## METHODS

### Sampling

A 94 $km^2$ grid was established with lines 1.6 km apart, centering on Jeff's Reef. At each of the 48 grid intersections, surficial sediment was collected by Petersen or Smith-Macintyre grab from R/V SEA DIVER in 1980. Using a table of random numbers, four station on N-S and E-W lines through Jeff's Reef were identified and three replicate grabs were taken at each station. Water depth was recorded from the winch readout and navigation used LORAN-C.

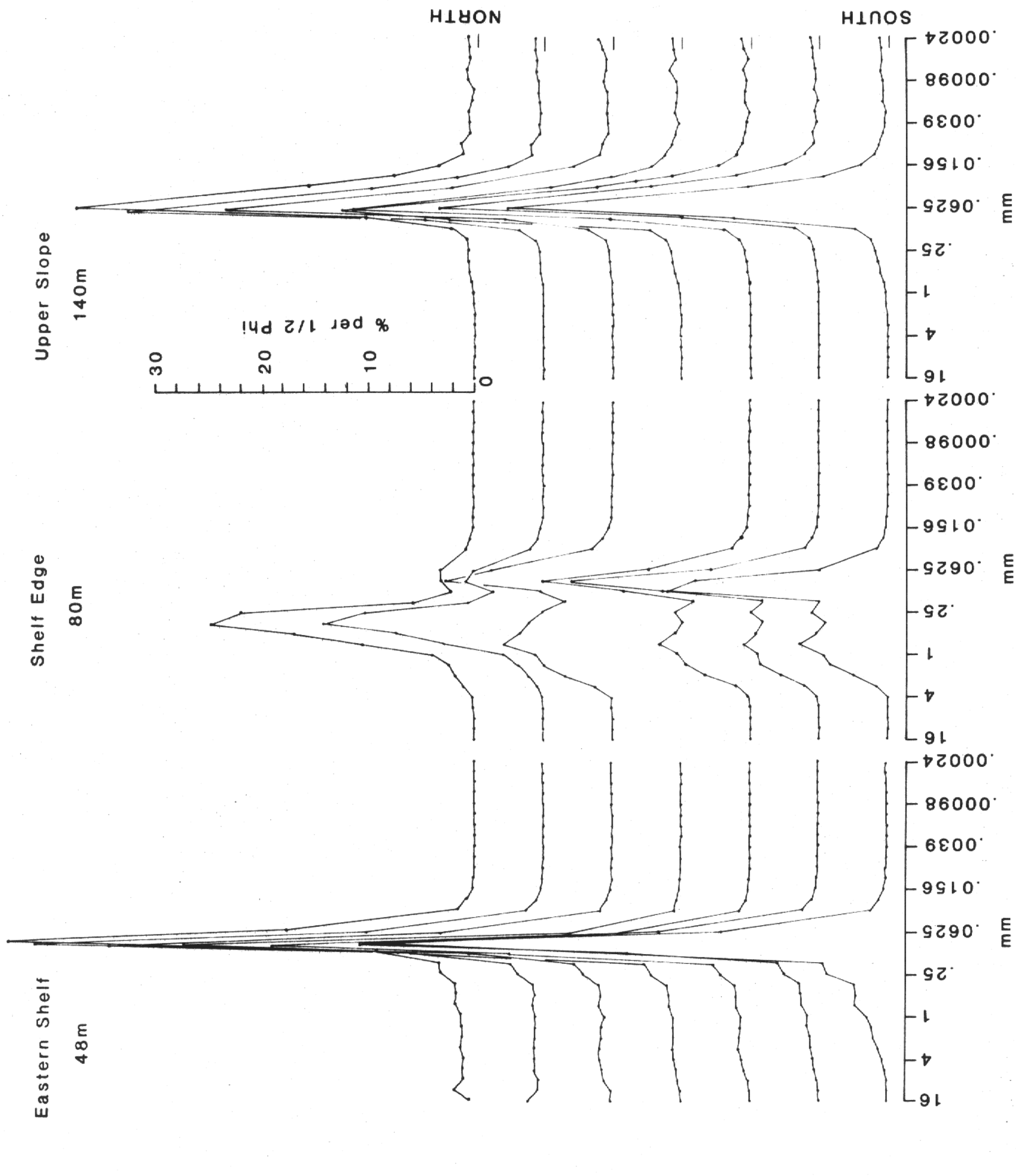


Figure 2 Size frequency curves for easter shelf, shelf edge and upper slope sediments. Location of Jeff's Reef is center of diagram. Zero y-axis intercept is right end of each curve or bar beneath right end for upper slope sediments.

At Jeff's Reef, surficial sediment was collected from 19 stations with a 19 x 19 cm clam-shell grab mounted on the manipulator arm of the JOHNSON-SEA-LINK (J-S-L) submersibles (Busby Associates 1981). Two stations 30 m apart on the SW corner of the reef were sampled with five replicate grabs from each station. Grab samples were dumped in the mouth of a 25 x 25 cm metal funnel which opened into a 3.5 l plexiglass cylinder. Twelve of these cylinders were connected by a plastic chain and hydraulically rotated beneath a clear plastic cover so that only one cylinder was open to the funnel at a given time. All sediment samples were stored frozen, unpreserved in polyethylene bags. Current and temperature were measured with ENDECO type 105 and 109 meters which were moored 2 m off the bottom at the base of Jeff's Reef for over a year. The current meter integrates speed and direction, separately, over 0.5 hour intervals so that instantaneous currents are not recorded.

**Lab Analysis**

Each sample was digested in commercial bleach at ambient temperature and wet sieved at (63$\mu$m). Dry sieve analysis of particles retained from wet sieving was done with 20 cm stainless steel sieves at one-half Phi intervals between 16 and 0.0625 mm. Sieves were agitated for 10 minutes by RO-TAP and each fraction weight was recorded to 0.01 g. Mud fractions (<63$\mu$m) were analyzed by SEDIGRAPH. Weight percent gravel, sand, silt, clay and mud, and grain size descriptors of sorting, skewness and normalized kurtosis (Folk and Ward 1957) were calculated. Size frequency curves were drawn by CALCOMP plotter. Grain size modes were obtained visually from size frequency curves. Using sieves, particles from >4, 3.9-0.35, 0.34-0.125 and <0.125 mm were obtained from samples known to have clear-cut grain size modes in those size fractions. Microscopic inspection identified the most abundant constituent particles in each fraction. This procedure follows the assumption that each peak in a size frequency distribution indicates the presence of a discrete grain population (Dauphin 1980).

Grain-type composition of the sand fraction (2-0.0625 mm) was further investigated by point-counting of petrographic thin sections. Riffle-split aliquots of sand were examined from N-S and E-W lines through Jeff's Reef (Fig. 1,16 samples 512-776 grains per slide) and 12 samples from Jeff's Reef (579-774 grains per slide). Weight percent $CaCO_3$ was measured by carbonate bomb (Schink et al. 1979) for aliquots of sand and mud (gravel was 100% $CaCO_3$). Sixteen non-reef and 20 reef samples were analyzed.

**Statistical analysis**

Arcs in transformation was made for all percentage data. Homogeneity of variance was measured by the F-max test and for those data sets with heterogeneous variance, the t-estimator test was used (Sokal and Rohlf 1969). For shelf sediment, variance within and between stations was determined by a two-way ANOVA. Significance of geographic variations in sediment parameters was determined by two-way ANOVA. The shelf area surrounding Jeff's Reef was divided into quadrants (NE, SE, NW, SW), each containing nine stations, and sediment parameters for these and for reef samples were compared by Student's t-test. Reef sediments were grouped into sub-environments by visually-determined similarity of size frequency curves and by geography; t-tests were used to identify any significant differences ($p<0.05$) in grain size parameters. The Mann-Whitney U-Statistic was used to determine significant differences between reef and non-reef samples for the thin-section point analysis.

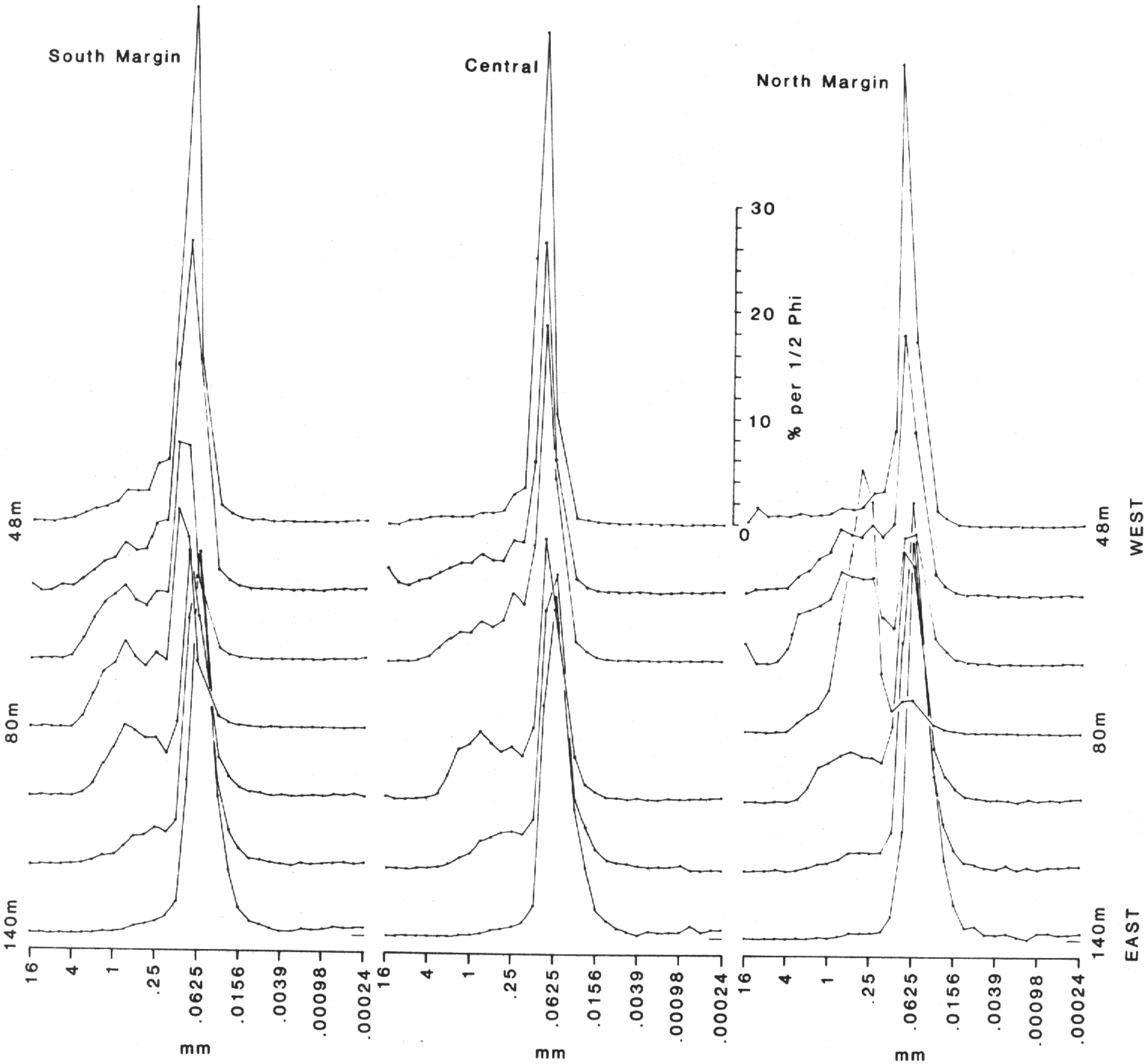


Figure 3 Size frequency curves in an east to west perspective, starting with upper slope sediments, across the shelf edge and ending with shelf sediments. Location of Jeff's Reef is center of diagram. Zero y-axis intercept is right end of each curve or bar beneath right end for 140 m sediments.

## RESULTS

### Bathymetry

Contours extend N-S (Fig. 1) and the sea floor slopes eastward to the Florida Straits. For 4.8 km west of Jeff's Reef the slope is 0.4o, steepening to 0.6o for 4.8 km east of the reef. Jeff's Reef rises 16 m from a base at 80 m, extending 230 m E-W and 100 m N-S. East of Jeff's Reef, the continental shelf edge is sinuous in plan view. The area surrounding Jeff's Reef is the eastern part of the continental shelf, the shelf edge, and upper continental slope. For convenience these environments will be designated as non-reef areas.

### Currents

Data for 289 days in 1978-79 with measurement periods in each month found three main paths of flow; east-west (tidal), north (Florida Current) and south (bottom counter current). Average east and west flow was 9.7 (5-15) and 6.2 (3-13) cm $sec^{-1}$, respectively. Average north and south flow velocities were similar, 7.5 (1-12) and 9.9 (3-17) cm $sec^{-1}$, respectively. Ignoring direction, current velocity equalled or exceeded 15 cm $sec^{-1}$ 17.3 percent of the time for winter months (October through March) and 11.2 percent for summer. With reference to an area of 1.0 $m^2$, total volume of flow was 2511 x $10^3 m^3 yr^{-1}$, of which 16% was to the north and 11% was to the south.

### Grain size modes

Size frequency curves afford easy visualization of sediment descriptors and illustrate sediment changes with physiography (Figs. 2,3,4). A ubiquitous grain size mode at 5 phi was found to be an artifact caused by the change in analytical methods at 4 phi (Griffiths 1957). The spurious nature of the 5 phi mode was identified by uninterrupted particle size analysis (SEDIGRAPH) between 3.5 and 6.5 phi for five selected samples. In this report, size frequency curves are smoothed by connecting the 4.0 and 5.0 phi data points with a straight line. All other size intervals are shown without smoothing.

Comparison of size frequency curves for all samples revealed that peaks and dips of particle abundance could be used to separate the size distributions into five size ranges, >16-4, 3.9- 0.35, 0.34-0.125, 0.124-0.0156, and <0.0155 mm (Fig. 4). Microscopic inspection showed that particles >4mm were pelecypods (shelf) or coral branches (reef) particles 3.9-0.035 mm were valves of the pelecypod (*Nuculana acuta*) plus shell hash, particles 0.34-0.125 mm were mostly foraminifera, particles 0.124- 0.0156 mm were quartz plus lithified carbonate pellets, and particles <0.0155 mm were designated as fines, but not otherwise identified.

### Non-reef sediments

Within-station variance for all sediment descriptors was significantly smaller ($p<0.05$) than between-station variance for the four stations with replicate samples (Fig. 1). Because these four stations were chosen at random, we assume ANOVAs of additional sets of randomly chosen stations would also show within-station variance to be smaller than between-station variance. Based on this assumption we treat any significant ($p<0.05$) between-station differences to be real. For all non-reef stations (n = 48) results of the two-way ANOVA indicated that for all sediment descriptors, there were significant differences ($p<0.05$) east to west (Fig. 2) and no significant differences south to north (Fig. 3). Shelf sediments are sand (51-93 percent) containing 0.03-14 percent gravel, 3-40 percent silt and 1-9 percent clay (Table 1).

The major grain size differences between upper slope, shelf edge and eastern shelf sediments were a decrease in mud from 28- 29 percent to 6-8 percent, an increase in gravel from

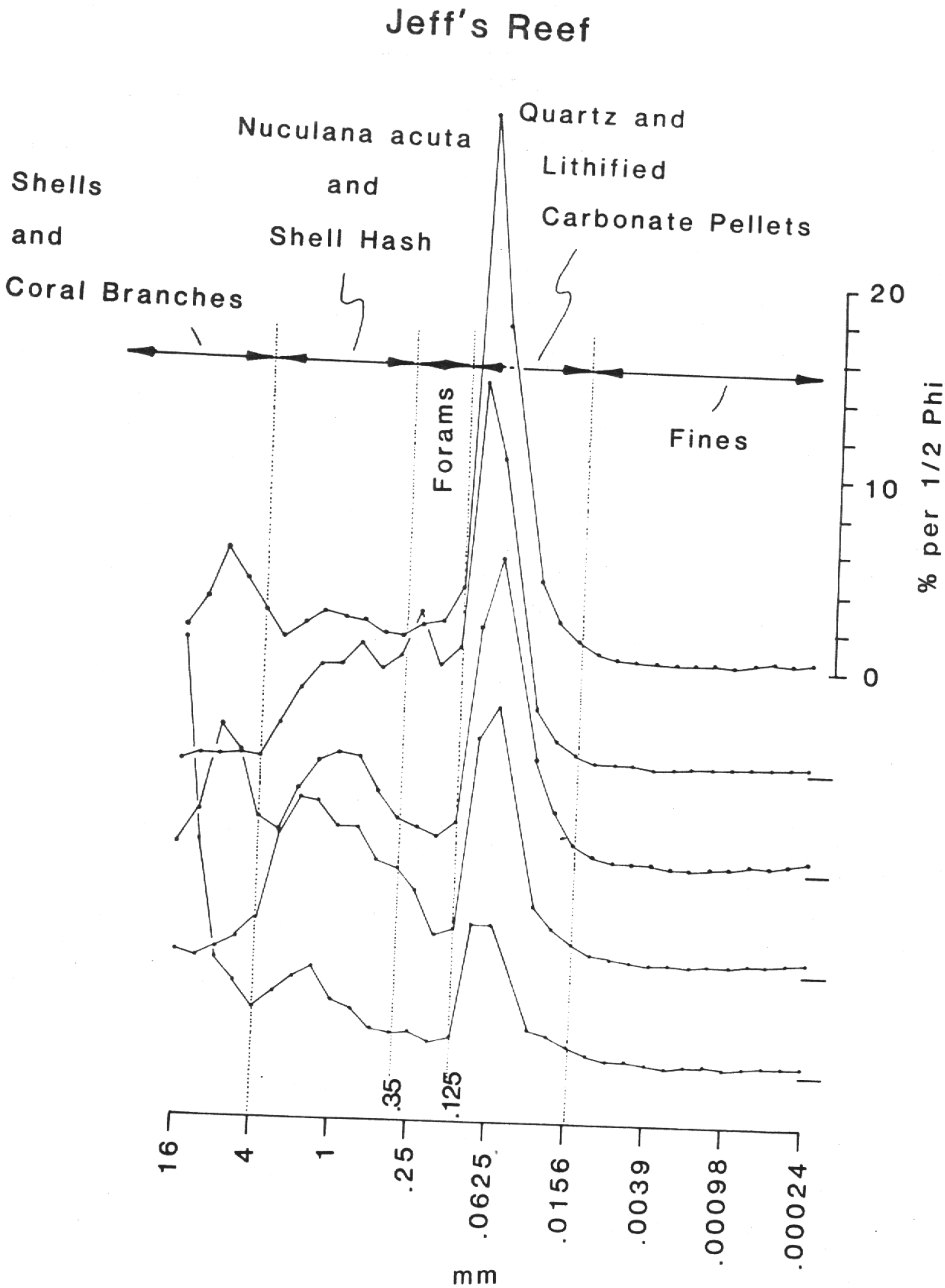


Figure 4 Size frequency curves for selected samples from Jeff's Reef. Curves are divided into five size ranges, each of which is dominated by the type of constituent grain indicated. Zero y-axis intercept is a bar beneath right end of each curve.

less than 1 percent to 4-8 percent, and dominance of fine gravel and very coarse sand in shelf edge sediments (Figs. 2,3; Table 1).

Mean calcium carbonate content of shelf-edge sediment was 79 percent (74-86 percent) and this decreased by gradation for both upper slope (37 percent) and eastern shelf (58 percent). Major compositional elements for the entire size spectrum were identified through inspection of five size fraction (Fig. 4) portrayed in map format (Fig. 5) and by thin section point counts of the sand fraction. Shells (>4mm) comprised 1-8 percent of the northwest shelf. The pelecypod *Nuculana acuta* and shell hash (3.9-0.35 mm) formed 30-60 percent of a three km wide N-S band of the shelf-edge sediment. Abundance of quartz and lithified carbonate pellets was greatest in upper slope (>80 percent) and eastern shelf sediments (50-70 percent). Fines (<0.0155 mm) exceeded 10 percent only in upper slope sediments.

For the sand fraction (2-0.0625 mm), point counting revealed eleven grain types, in volume percent and in order of decreasing abundance, detrital silicates $25.7 \pm 11$ percent; molluscs $23.0 \pm 8.6$; pellets $10.6 \pm 4.2$; ooids $9.4 \pm 5.3$; carbonate rock fragments (oosparite and biomicrite) $4.5 \pm 6.9$; barnacles $2.2 \pm 1.7$; echinoderms $2.2 \pm 0.8$; coralline algae $0.3 \pm 0.4$; coral $0.2 \pm 0.4$; and unknowns $11.0 \pm 6.5$. Bryozoans and spicules from gorgonians, sponges and tunicates were present in trace amounts.

**Reef sediments**

The only significant difference in sediment grain size descriptors for the reef stations with replicate samples (Fig. 1) was for kurtosis; therefore, all reef stations will be treated as representing one environment. Reef sediments are sands ($\bar{x}$=61.8 percent) with major amounts of gravel ($\bar{X}$=23.8 percent) and lesser amounts of silt ($\bar{X}$=10.2 percent) and clay ($\bar{X}$=4.1 percent).

Mean carbonate content of the reef sediment was 70 percent 59-90 percent). The main compositional elements as estimated through grains size modes were coral branches $\bar{X}$ = 19 percent by wt., *Nuculana acuta* and shell hash $\bar{X}$ = 27, quartz and lithified carbonate pellets $\bar{X}$ = 39, and fines $\bar{X}$ = 6, (Fig. 5). Point counting of the sand fraction indicated, in volume percent and in order of decreasing abundance, detrital silicates $26.8 \pm 10.3$ percent; molluscs $23.6 \pm 12.6$; foraminifera $12.2 \pm 5.4$; barnacles $7.3 \pm 6.6$; pellets $6.7 \pm 4.1$; ooids $4.3 \pm 2.3$; carbonate rock fragments $3.8 \pm 4.0$; echinoderms $3.3 \pm 1.8$; coral $1.1 \pm 0.9$; coralline algae $0.2 \pm 0.2$; and unknowns $10.0 \pm 3.6$.

## DISCUSSION

**Grain types**

Gravel from Jeff's Reef is mostly broken *Oculina* branches, not present in non-reef sediments (Fig. 5). Reef sand contains significantly more ($p<0.05$) barnacles and coral, and less ooids and pelets than non-reef sand. Sand from the reef top contained significantly more barnacles and coral fragments, and less molluscs and carbonate rock fragments than the reef base. Reef and non-reef sands were similar in content of detrital silicates, echinoderms and coralline algae.

Shelf-edge *Oculina* reefs are more similar to deep-water *Lophelia* banks than shallow-water coral reefs in structure and function; both *Oculina* and *Lophelia* banks consist primarily of a single species of aposymbiotic coral and form thickets on topographic highs in regions where upwelling or currents supply nutrients. However, sediment components of this *Oculina* reef are comparable to hermatypic reefs (Table 2) in abundances of coral, molluscs and foraminifera. The absence of calcareous green algae is due to the low intensity of light energy at such depths.

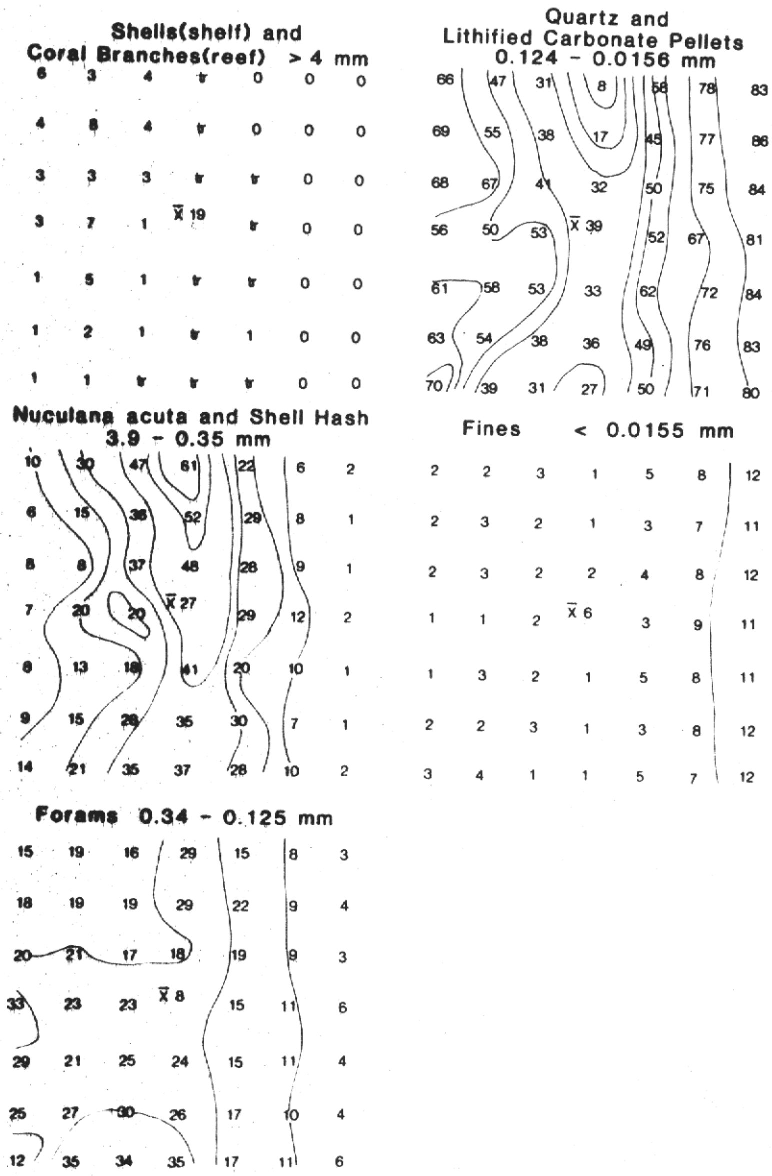


Figure 5 **Geographic distribution** of the five constituent grain types (wt. %, identified in Fig. 4) **from reef and shelf** areas. Contour interval 10%. Jeffs'Reef is at center with X= mean **for all reef samples**; other numbers represent individual samples.

TABLE 1. Grain size descriptors and t-test results for shelf quadrants against Jeff's Reef.

| | Jeff's Reef n = 19 | NW Shelf n = 9 | NE Shelf n = 9 | SW Shelf n = 9 | SE Shelf n = 9 |
|---|---|---|---|---|---|
| Gravel[1], mean, ± S. D. | 23.8 ± 17.0 | 8.5 ± 3.2 | 0.99 ± 1.1 | 4.5 ± 1.8 | 0.90 ± 0.9 |
| Range | 1.3 - 70.5 | 4.8 - 13.7 | 0.03 - 3.3 | 2.7 - 8.3 | 0.1 - 2.8 |
| Sand[2] | 61.8 ± 15.4 | 83.7 ± 4.1 | *69.7 ± 13.8 | 89.2 ± 2.5 | *71.0 ± 12.2 |
| | 22.9 - 83.8 | 77.2 - 89.1 | 51.0 - 87.0 | 84.1 - 92.5 | 53.7 - 85.8 |
| Silt[3] | 10.2 ± 4.1 | 5.8 ± 1.2 | 23.5 ± 12.4 | 4.4 ± 1.1 | 22.3 ± 10.9 |
| | 3.2 - 18.3 | 3.6 - 7.0 | 8.2 - 39.7 | 2.7 - 5.8 | 8.8 - 37.7 |
| Clay[4] | 4.1 ± 1.9 | 2.0 ± 0.2 | *5.8 ± 2.4 | 1.8 ± 0.6 | 5.8 ± 2.2 |
| | 1.5 - 8.6 | 1.8 - 2.3 | 2.7 - 9.3 | 1.0 - 2.8 | 2.6 - 8.9 |
| Mud[5] | 14.3 ± 5.6 | 7.8 ± 1.3 | 29.3 ± 14.8 | 6.3 ± 1.6 | 28.1 ± 13.0 |
| | 4.7 - 24.2 | 5.5 - 9.0 | 11.0 - 49.0 | 3.7 - 8.6 | 11.4 - 46.2 |
| I[6] | 2.84 ± 0.62 | 1.68 ± 0.39 | 1.77 ± 0.11 | 1.40 ± 0.31 | 1.79 ± 0.08 |
| | 1.90 - 4.31 | 1.14 - 2.10 | 1.60 - 1.93 | 0.83 - 1.77 | 1.70 - 1.93 |
| $SK_I$[6] | -0.09 ± 0.34 | -0.46 ± 0.21 | +0.20 ± 0.47 | -0.49 ± 0.06 | *+0.16 ± 0.49 |
| | -0.67 to +0.37 | -0.70 to -0.01 | -0.45 to +0.71 | -0.60 to -0.37 | -0.44 to +0.75 |
| $K'_G$[6] | 0.53 ± 0.12 | *0.63 ± 0.17 | 0.68 ± 0.12 | 0.63 ± 0.11 | 0.68 ± 0.12 |
| | 0.41 - 0.86 | 0.45 - 0.83 | 0.50 - 0.81 | 0.44 - 0.78 | 0.48 - 0.81 |

* not significant, $p < 0.05$
1 particles > 2.00 mm
2 particles 2.00- 0.0625 mm
3 particles 0.0625- 0.0039 mm
4 particles < 0.0039 mm
5 Silt plus Clay
6 formulae of Folk and Ward (1957)

Table 2. Constituent sand grains from selected reefs.

| Grain type | Hermatypic Reefs: Abaco, Bahamas[1] (Storr, 1964) | Hermatypic Reefs: Alacran, Gulf of Mexico[1] (Hoskin, 1963) | Hermatypic Reefs: Bermuda[1] (Neumann, 1965)[1] | Hermatypic Reefs: Florida Reef Tract[1] (Ginsburg, 1956) | Aposymbiotic Reefs: Lophelia banks[2] Blake Plateau (Stetson et al. 1962) | Aposymbiotic Reefs: Rockall Bank[3] (Scoffin et al. 1980) | Aposymbiotic Reefs: Jeff's Reef (this study) |
|---|---|---|---|---|---|---|---|
| Coral | 34 | 29 | 3 | 13 | 28-39 | 0 | 1 |
| Mollusc | 14 | 8 | 68 | 17 | 0-1 | 6 | 24 |
| Foraminifera | 14 | 6 | 5 | 11 | 13-39 | 44 | 12 |
| Calcareous green algae | 20 | 35 | 11 | 30 | | 0 | 0 |
| Calcareous red algae | 12 | 8 | | 9 | | 0 | 0.2 |
| Barnacles | | 0 | | | | tr | 7 |
| Echinoderms | | tr | | | | 4 | 3 |
| Bryozoans | | 0 | | | | 4 | tr |
| Calcareous non-skeletal | | 13 | | | | | 15 |
| Detrital silicates | | 0 | | | 0 | 33 | 27 |
| Other | 6 | 1 | 5 | 20 | 21-59 | 9 | 10 |

1 Emery and Uchupi, 1972, Table 15, p. 353
2 Samples 4 and 11, Stetson et al., 1962, Table 2, p. 14
3 Mean of samples 53 and 81 (chosen for presence of Lophelia), Scoffin et al., 1980, Appendix, p. 355

Sediments of the study area are mixtures of modern and relict particles although regionally, Emery (1966) suggested a modern age and Milliman et al. (1972) suggested a relict age. Our observations from J-S-L submersibles indicate that *Oculina* coral gravel on Jeff's Reef comes from living *Oculina* coral colonies. An *Oculina* branch from a depth of 8-12 cm in a core taken by a lock-out diver (JKR) on Jeff's Reef was found to have a radiocarbon age of 480$\pm$70 years B.P. Ages of the shell hash, foraminifera, quartz, lithified carbonate pellets, and fines are not known. The quartz is probably relict (Emery ,1968); the pellets, ooids and carbonate rock fragments probably come from underlying limestones of Holocene age (Macintyre and Milliman 1970, Table 3, and p. 2593). All carbonate constituents are mixtures of bright, clean particles and gray-stained, microbored grains. Large shells on the shelf are mostly scallops (*Argopecten gibbus*) and a scallop fishery is periodically active on the eastern shelf (Allen and Costello 1972). The most abundant smaller mollusc in the 3.9-0.35 mm size fraction is the pelecypod (*Nuculana acuta*) which also lives on the eastern Florida shelf (Paul Mikkelsen, personal communication, 1982). The N-S band of *N. acuta* and shell hash along the shelf edge (Fig. 5) may be the product of a pause in the Holocene transgression (Macintyre and Milliman 1970). However, echo- sounding profiles across that part of the shelf-break show no terrace (Avent et al. 1977, Fig. 5, p. 192).

**Mud trapping**

Sediment of Jeff's Reef contains an average of 14.3 percent mud whereas sediments at the same depth, but a few kilometers north and south, contain an average of 4.6 percent mud. Nearby shelf sediments to the NW and SW in 50-80 m depths contain 6-8 percent mud (Table 1). The origin of the reef-accumulated mud is not well understood; it appears as if some is generated within the reef and some is allochthonous, trapped by the reef. Much of the carbonate is probably generated by microborers as shown for *Lophelia* coral on Rockall Bank by Scoffin et al. (1980). Mechanical abrasion of coral rubble is also a source of fine carbonate particles as evidenced by the smoothed *Oculina* branches on the reef top. Mud-trapping may be caused by some process of living reefs, as suggested by Stetson et al. (1962), Neumann et al. (1977) and Mullins et al. (1981) for various deep-water reefs. Dead shelf-edge carbonate pinnacles (without coral framework) in the Gulf of Mexico contain less mud than surrounding sediments (Ludwick and Walton 1957, Fig. 12, p. 2073).

**Sediment export from the reef**

The amount of carbonate particles exported from Jeff's Reef is too small to build noticeable sediment shadow deposits which might be expected on the reef's northern side. Coral branches are abundant in reef sediment (up to 70 percent by wt.) but are not present in shelf sediments 1.6 km away on all sides. Some export does occur as shown by fresh coral sand present in non-reef environments ($\overline{X}$ = 0.2 percent by volume, Table 2). Although concentrated on the reef top, barnacle sand in non-reef environments does not indicate transport from the reef because, unlike *Oculina*, barnacles are presently growing on shells and shell hash in non-reef areas.

Measured current velocities (>15 cm sec$^{-1}$) are high enough to cause erosion and suspension transport near the reef for 49 of 289 days (17 percent). Pockets of sediment 4-9 m above the reef base containing quartz sand and silt, ooids, pellets and carbonate rock fragments show that local erosion and transport have occurred. Our observations from the J-S-L submersibles of the sea floor at Jeff's Reef have encountered no ripples or dunes. As current velocities are sufficient to build these bedforms, their absence may be due to intense bioturbation caused by an abundant sea cucumber *Holothuria lentiginosa* in densities of 2.2m$^{-2}$ (Pawson et al., 1982).

## CONCLUSIONS

1. Jeff's Reef is a 16 m high topographic structure built by living *Oculina* coral and is an area of modern coarse-grained carbonate sedimentation.

2. Sediment from the 94 $km^2$ area surrounding Jeff's Reef is dominated by relict detrital quartz, mollusc, and ooids + pellets + carbonate rock fragment sand.

3. Particle size distribution and constituent grains of upper continental slope, shelf edge, and easternmost continental shelf change east to west, but not north to south.

4. Reef sand contains more barnacles and coral, and less ooids and pellets than non-reef sand.

5. Jeff's Reef sand has a diversity of grain types comparable to shallow-water hermatypic reefs except for the absence of green calcareous algae.

6. The living coral structure traps mud. The reef contains an average of 14.3 percent silt plus clay as contrasted with an average of 4.6 percent silt plus clay in sediments from the same water depths in non-reef areas 1.6 km away in all directions.

7. Coral branch gravel is not transported from Jeff's Reef, but export of small amounts of coral sand has been detected.

## ACKNOWLEDGEMENTS

We thank the officers and crews of R/V JOHNSON, R/V SEA DIVER, and the J-S-L submersibles for their expert assistance at sea, John Holt for fabricating sampling devices, and John Miller for replicate samples from Jeff's Reef. Henry T. Mullins and Wolfgang Schlager read an earlier draft of the manuscript. This is contribution number 617 from the Harbor branch Oceanographic Institution, Inc.

## REFERENCES

Allen, D.M., and Costelle, T.J., 1972, The Calico Scallop, Agopecten gibbus: NOAA Tech. Report NMFS SSRF-656, 19p.

Avent, R.M., King, M.E., and Gore, R.H., Topographic and faulnal studies of shelf-edge prominences off the central eastern Florida coast: Int.Revue ges. Hydrobiol., v. 62, p. 185-208

Avent, R.M., and Stanton, F.G., 1979, Observation on the continental margin off central eastern Florida: Harbor Branch Fnd. Tech. Rept. No. 25, 40 p.

Busby Associates, 1981, Undersea vehicles directory: Busby Assoc., Inc., Arlington, Va. 399 p.

Dauphin, J.P. 1980, Size distribution of chemically extracted quartz used to characterize fine-grained sediments: Jour. Sed. Petrology, v. 50, p.205-214.

Emery, K.O., 1966, Atlantic continental shelf and slope of the United States - geologic background: U.S. Geol. Surv. Prof. Paper 529-A, 23 p.

Emery, K.O., 1968, Relict sediments on continental shelves of world: American Assoc. Petroleum Geol. Bull., v. 52, p. 445-464.

Emery, K.O., and Uchupi, E., 1972, Western North Atlantic Ocean; Topography, Rocks, Structure, Water Life, and Sediments: American Association of Petroleum Geologists, Memoir 17, Tulsa, Oklahoma, 532 p.

Folk, R.L., and Ward, W.C., 1957, Brazos River Bar: a study in the significance of grain size parameters: Jour. Sed. Petrology. v. 27, p. 3-26.

Ginsburg, R.N., Lloyd, R.M., Stockman, K.W., and McCallum, J.S., 1965, Shallow-water carbonate sediments, Hill, M.N., ed., The Sea: Interscience, N.Y., p. 554-582.

Gorsline, D.S., 1963, Bottom sediments of the Atlantic shelf and slope off the southern United States: Jour. Geol., v. 71, p. 422-440.

Griffiths, J.C., 1957 (Abstract), Size-frequency distribution of detrital sediments based on sieving and pipet sedimentation: Bull, Geol. Soc. America, v. 68, p. 1739.

Ludwick, J.C., and Walton, W.R., 1957, Shelf-edge calcareous prominences in northeastern Gulf of Mexico: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 2054-2101.

MacIntyre, I.G., and Milliman, J.D., 1970, Physiographic features on the outer-shelf and upper continental slope, Atlantic continental margin, southeastern United States: Geol. Soc. America Bull., v. 81, p. 2577-2598.

Milliman, J.D., Pilkey, O.H., Ross, D.A., 1972, Sediment of the continental margin off the eastern United States: Geol. Soc. America Bull., v. 83, p. 1315-1334

Moe, M.A., 1963, A survey of offshore fishing in Florida: Florida State Board Cons., Prof. Paper Ser. No. 4, p. 1-115.

Mullins, H.T., Newton, C.R., Heath, K., and Van Buren, H.M., 1981, Modern deep-water coral mounds north of Little Bahama Bank: criteria for recognition of deep-water coral bioherms in the rock record: Jour. Sed. Petrology, v. 51, p. 999-1013.

Neumann, A.C., Kofoed, J.W., and Keller, G.H., 1977, Lithoherms in the Straits of Florida: Geology, v. 5, p. 4-10.

Pawson, D.L., Miller, J.E., and Hoskin, C.M., 1982 (Abstract), Distribution of Holothuria Lentiginosa enodis Miller and Pawson in relation to a deep-water Oculina reef off Fort Pierce, Florida (Echinodermata: Holothuroidea), Lawrence, J.M., ed., Echinoderms: Proc. Internat'l Conf., Tampa Bay: Balkema, Rotterdam, p. 321.

Reed, J.K., 1980, Distribution and structure of deep-water Oculina varicosa coral reef off central eastern Florida: Bull. Mar. Sci., v. 30, p. 667-677.

Reed, J.K., In situ growth rates of the scleractinian coral Oculina varicosa occurring with zooxanthallae on 6-m reefs and without on 80-m banks, In Gomex, E.D., ed., Proc. Fourth Internat'l Coral Reef Symp., Univ. of the Philippines, p. 201-206.

Reed, J.K., Gore, R.H., Scotto, L.E., and Wilson, K.A., 1982, Community composition, structure, areal and trophic relationships of decapods associated with shallow- and deep-water Oculina varicosa coral reefs: Bull. Mar. Sci., v. 32, p. 761-786.

Schink, J.C., Stockwell, J.H., and Ellis, R.A., 1979, An improved device for gasometric determination of carbonate in sediment: Jour. Sed. Petrology, v. 49, p. 651--653.

Scoffin, T.P., Alexandersson, E.T., Bowes, G.E., Clokie, J.J., Farrow, G.E., and Milliman, J.D., 1980, Recent, temperate, sub-photic, carbonate sedimentation: Rockall Bank, Northeast Atlantic: Jour. Sed. Petrology, v. 50, p. 331-356.

Shinn, E.A., Hudson, J.H., Malley, R.B., and Lidz, B., 1977, Topographic control and accumulation rate of some Holocene coral reefs, south Florida and Dry Tortugas, in Taylor, D.L., ed., Proc. Third Internat'l Coral Reef Symp., p. 1-7.

Smith, N.P., 1982, Upwelling in Atlantic shelf waters of south Florida: Florida Scientist, v. 45, p. 125-138.

Sokal, R.R., and Rohlf, F.I.J., 1969, Biometry: W.H. Freeman, San Francisco, 776 p.

Stetson, T.R., Squires, D.F., and Pratt, R.M., 1962, Coral banks occurring in deep water on the Blake Plateau: American Mus. Novitates, No. 2114, 40 p.

Teichert, C., 1958, Cold and deep water coral banks: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 1064-1082.

Thompson, M.J., and Gilliland, L.E., 1980, Topographic mapping of shelf edge prominences off southeastern Florida: Southeastern Geol., v. 21, p. 155-164.

Uchupi, E., 1969, Morphology of continental margin off southeastern Florida: Southeastern Geol, v. 11, p. 129-134.